FIRST HOST RECORD FOR *PTEROMALUS CARDUI* (HYMENOPTERA: PTEROMALIDAE) ON *UROPHORA QUADRIFASCIATA* (DIPTERA: TEPHRITIDAE) IN SPOTTED KNAPWEED (*CENTAUREA BIEBERSTEINII*, ASTERACEAE) IN MICHIGAN, U.S.A.[1]

Jordan M. Marshall,[2,3] Roger A. Burks,[4] and Andrew J. Storer[2]

ABSTRACT: An association between the biological control agent *Urophora quadrifasciata* and a parasitoid, *Pteromalus cardui,* was found within seed heads of spotted knapweed *(Centaurea biebersteinii)* in Michigan, U.S.A. There was a significant correlation between the percentage seed heads with *U. quadrifasciata* emerging and those with *P. cardui* emerging. This parasitoid might reduce the already limited effectiveness of *U. quadrifasciata* in controlling spotted knapweed.

KEY WORDS: *Pteromalus cardui,* Hymenoptera, Pteromalidae, *Urophora quadrifasciata,* Diptera, Tephritidae, spotted knapweed, *Centaurea bierberteinii,* Asteraceae, Michigan, U.S.A.

Classical biological control of exotic pestiferous organisms involves the importation and release of their natural enemies, with each release intended to reduce the population size of the targeted species (e.g. Pedigo 1999, Speight et al. 1999). Prior to release of the biological control agents, host specificity tests are carried out under quarantine conditions to minimize the likelihood of the agent having unacceptable impacts on nontarget species. During the quarantine period, biological control agents are sterilized to ensure the agents are not carrying a pathogen, parasite, or predator of their own that would result in a failure of the biological control program (APHIS-PPQ 2003). Even with such measures in place to increase the chances of a biological control agent, predators or parasites native to the release location may become problematic for the agent.

Spotted knapweed, *Centaurea biebersteinii* de Candolle (= *C. maculosa* auct. non Monnet de la Marck) (Asteraceae), is considered one of the most economically destructive weeds in rangelands of western North America (Harris and Cranston 1979). It can be found throughout the contiguous United States, Alaska, Hawaii, and in all Canadian provinces except the Northwest Territories and Nunavut. Ecological impacts imposed by spotted knapweed include increasing sedimentation and runoff, decreasing native plant diversity, and decreasing forage quality for grazers (Lacey et al. 1989, Kedzie-Webb et al. 2001, Olson and Wallander 2001).

[1] Received on May 13, 2004. Accepted on November 12, 2004.

[2] School of Forest Resources and Environmental Science, Michigan Technological University, Houghton, MI 49931, U.S.A. E-mail: (AJS): storer@mtu.edu.

[3] Current Address: Department of Forestry, Wildlife, and Fisheries, University of Tennessee, Knoxville, TN 37996, U.S.A. E-mail: marshall@utk.edu.

[4] Department of Entomology, University of California, Riverside, CA 92521, U.S.A. E-mail: rogerburks@yahoo.com.

Mailed on March 15, 2005

Urophora quadrifasciata (Meigen) (Diptera: Tephritidae) is a Palearctic seed head gall fly introduced from the Krasnodar Territory, Russia, into British Columbia, Canada, in 1972 as a biological control agent for spotted and diffuse knapweed, *C. diffusa* Monnet de la Marck (Asteraceae) (Harris 1980a). Over the past 30 years, subsequent releases in several American states and Canadian provinces have allowed *U. quadrifasciata* to spread through much of the northern range of spotted and diffuse knapweeds (Story 2002). In addition to these releases, the dissemination of *U. quadrifasciata* is aided by its ability to disperse over large distances and locate remote patches of knapweed (Harris 1986, Mays and Kok 2003). It develops within seed heads by diverting energy from the plant to larval maturation by inducing gall production in the plant (Burkhardt and Zwölfer 2002).

U. quadrifasciata has an obligate second generation that overwinters in the seed head as late-instar larvae and emerges the following May-June (Myers and Harris 1980, Harris 1980a). A high supercooling capacity (down to -35°C) enables the larvae to survive at extremely low temperatures, providing an extension of suitable habitat into areas experiencing extended periods of exceptionally cold weather (Story et al. 1993).

Larval mortality within spotted knapweed seed heads is often caused by direct predation by several bird and small mammal species, as well as indirect consumption by deer grazing on seed heads (Story et al. 1995). In April 2003, *Pteromalus cardui* (Erdös) (Hymenoptera: Pteromalidae) (Dzhanokmen and Grissell 2003), a Palearctic parasitic wasp, was reared from spotted knapweed seed heads collected at locations in Houghton County, Michigan. During this time, *U. quadrifasciata* adults were also reared from seed heads collected from the same locations.

Pteromalus cardui has been recorded from Britain, Hungary, Kazakhstan, and The Czech Republic (Graham 1969; Dzhanokmen 1987, 2001). It has been reported to parasitize the tephritids *Tephritis dilacerata* (Loew) and *Ensina sonchi* (Linnaeus) on *Sonchus arvensis* Linnaeus (Asteraceae), as well as other *Tephritis* spp. on *Ptarmica cartilaginea* Ledebour (Asteraceae) (Dzhanokmen 2001). None of these fly hosts of *P. cardui* have been recorded from northern Michigan (Foote et al. 1993).

Following initial observations of the parasitoid emerging from spotted knapweed seed heads, studies were undertaken to (1) develop evidence that the parasitoid uses *U. quadrifasciata* as its host in spotted knapweed and (2) determine whether there is a relationship between emergence of the parasitoid and emergence of the seed head fly.

METHODS

Spotted knapweed plants were collected from 12 patches in Houghton County, Michigan, from 23 August to 14 November 2002, and stored at -8°C for 6 to 8 months, depending on the collection date. In April and May 2003, 660 seed heads

were randomly selected from the 12 sites and placed into vials to rear adult *U. quadrifasciata* and *P. cardui* at room temperature. Eight-dram plastic shell vials were half filled with wet sand topped with a layer of dry sand. Vials were covered with cotton fabric securing a single knapweed seed head inside, and they were monitored for insect emergence every 3 to 4 days. The identity of *U. quadrifasciata* adults was verified using White and Korneyev (1989) and voucher specimens (1 male and 1 female) of *P. cardui* have been deposited in the Insect Collection of the University of Michigan, Museum of Zoology.

The proportion of seed heads from which *P. cardui* emerged and from which *U. quadrifasciata* emerged was determined for each collection site, and relationships between these proportions were tested using correlation analysis of arcsine transformed data (arcsin$\sqrt{p}$) (Zar 1999).

RESULTS AND DISCUSSION

One hundred seventeen *P. cardui* adults emerged from the 660 spotted knapweed seed heads placed in rearing. Wasps were reared from seed heads collected at 9 of the 12 sites (Table 1), with the first adults emerging after 17 days. Fifty-four *U. quadrifasciata* adults also emerged from the 660 seed heads, with specimens reared from 8 of the 12 sites. On 9 occasions these flies emerged from the same seed head as a wasp (Table 1).

Table 1. Percentage of spotted knapweed seed heads from which *Urophora quadrifasciata* and *Pteromalus cardui* emerged alone, and those from which both *U. quadrifasciata* and *P. cardui* emerged. Seed heads were collected in Houghton County, Michigan, and insects emerged from May through July 2002 after overwintering.

Site (UTM Zone 16N)	No. of seed heads placed in rearing	*Urophora quadrifasciata*	*Pteromalus cardui*	Both spp.
1 (382178, 5219134)	50	0.0	4.0	0.0
2 (380817, 5219287)	52	0.0	0.0	0.0
3 (380634, 5219085)	50	0.0	0.0	0.0
4 (379830, 5218685)	25	4.0	8.0	0.0
5 (379672, 5219258)	25	12.0	44.0	4.0
6 (379990, 5219550)	78	3.8	6.4	2.6
7 (380159, 5210635)	50	0.0	12.0	0.0
8 (380549, 5218850)	55	1.8	0.0	0.0
9 (380338, 5218618)	97	9.3	29.9	1.0
10 (380338, 5218618)	20	40.0	30.0	10.0
11 (379739, 5218616)	49	6.1	20.4	2.0
12 (378375, 5221202)	109	10.1	11.9	1.8
Total	660	5.9	12.7	1.4

Of seed heads that yielded at least one *P. cardui,* the mean number emerging was 1.26 (SE = 0.07). Of seed heads that yielded at least one *U. quadrifasciata,* the mean number emerging was 1.13 (SE = 0.06). Thirty-five percent of *P. cardui* adults that emerged were reared from seed heads with one or more other adult *P. cardui.* Eleven *P. cardui* adults emerged from the 9 seed heads producing both *U. quadrifasciata* and wasps. No other insects emerged from seed heads from any of the sites. The proportion of seed heads from which *P. cardui* emerged at each site was correlated with the proportion of seed heads from which *U. quadrifasciata* emerged ($r = 0.7270$; $p < 0.01$).

The fifty-four *U. quadrifasciata* adults emerged resulted in 0.08 viable galls/seed head. Though Norwierski et al. (1987) described acceptable densities of *U. quadrifasciata* larvae as 0.5 gall/seed head, Harris (1980b) observed only 0.1 galls/seed head and reported a ninety-five percent reduction in seed production by *U. quadrifasciata,* in cooperation with *U. affinis.* This reduction in seed production is based on the assumption that each spotted knapweed plant produces an average of 416 seeds (16 seed heads/plant , x 26 seeds/seed head) (Watson and Renney 1974). A large number of seeds, 1300 to 1600 seeds/m^2, are still allowed to enter the seed bank with viability of up to eight years in the soil (Harris 1980b, Davis et al. 1993). In areas where *U. affinis* and *U. quadrifasciata* co-occur, *U. quadrifasciata* rapidly becomes the dominant species in knapweed patches (Mays and Kok 2003).

Even with *U. quadrifasciata* becoming well established, including areas such as the Upper Peninsula of Michigan where no releases have been made, a large number of seeds are not being destroyed and densities of spotted knapweed are not being reduced (Lang et al. 1997). Such ineffectiveness has been considered a biological control failure (Myers 2000). The limited effectiveness of *U. quadrifasciata* in reducing spotted knapweed seed production may be decreased further through parasitism by *P. cardui.*

ACKNOWLEDGEMENTS

The authors thank James A. Bethke (Department of Entomology, University of California, Riverside, CA) for review of this manuscript, Eric Grissell (Systematic Entomology Laboratory, Department of Entomology, National Museum of Natural History, Washington, DC) for identification of *P. cardui,* and Janet M. Aerts, Brian L. Beachy, Devin M. Donaldson, Elizabeth E. Graham, and Justin N. Rosenier for field and laboratory assistance.

LITERATURE CITED

APHIS-PPQ. 2003. Reviewer's Manual for the Technical Advisory Group for Biological Control Agents of Weeds: Guidelines for Evaluating the Safety of Candidate Biological Control Agents. US Department of Agriculture, Marketing and Regulatory Programs 02/2003-02 PPQ. Washington, D.C. 224 pp.

Burkhardt, B. and H. Zwölfer. 2002. Macro-evolutionary tradeoffs in the tephritid genus *Urophora:* benefits and costs of an improved plant gall. Evolutionary Ecology Research 4:61-77.

Davis, E. S., P. K. Fay, T. K. Chicoine, and C. A. Lacey. 1993. Persistence of spotted knapweed *(Centaurea maculosa)* seed in soil. Weed Science 41:57-61.

Dzhanokmen, K. A. 1987. Pteromalidae. pp. 88-411. *In,* G. S. Medevedev (Editor). Keys to the Insects of the European Part of the USSR, Vol. III: Hymenoptera, Part II. Amerind Publishing Co. Pvt. Ltd. New Delhi, India. 1341 pp.

Dzhanokmen, K. A. 2001. A Review of pteromalid wasps of the genus *Pteromalus* Swederus (Hymenoptera, Pteromalidae) from Kazakhstan: II. Entomological Review 80:472-496.

Dzhanokmen, K.A. and E.E. Grissell. 2003. Nomenclatural changes in Pteromalidae, with a description of the first New World species of *Ormocerus* Walker (Hymenoptera: Chalcidoidea). Proceedings of the Entomological Society of Washington 105:535-541.

Foote, R. H., F. L. Blanc, and A. L. Norrbom. 1993. Handbook of the Fruit Flies (Diptera: Tephritidae) of America North of Mexico. Cornell University Press, Ithaca, New York. 571 pp.

Graham, M. W. R. de V. 1969. The Pteromalidae of northwestern Europe Hymenoptera: Chalcidoidea). Bulletin of the British Museum (Natural History), Supplement 16:1-908.

Harris, P. 1980a. Establishment of *Urophora affinis* Frfld. and *U. quadrifasciata* (Meig.) (Diptera: Tephritidae) in Canada for the biological control of diffuse and spotted knapweed. Zeitschrift für Angewandte Entomologie 89:504-514.

Harris, P. 1980b. Effects of *Urophora affinis* Frfld. and *U. quadrifasciata* (Meig.) (Diptera: Tephritidae) on *Centaurea diffusa* Lam. and *C. maculosa* Lam. (Compositae). Zeitschrift für Angewandte Entomologie 90:190-201.

Harris, P. 1986. Biological control of knapweed with *Urophora quadrifasciata* Mg., Insects-Diseases-Pests, Canadex 641.613, Agriculture Canada, Ottawa. 2 pp.

Harris, P. and R. Cranston. 1979. An economic evaluation of control methods for diffuse and spotted knapweed in western Canada. Canadian Journal of Plant Science 59:375-382.

Kedzie-Webb, S. A., R. L. Sheley, J. J. Borkowski, and J. S. Jacobs. 2001. Relationships between *Centaurea maculosa* and indigenous plant assemblages. Western North American Naturalist 61:43-49.

Lacey, J. R., C. B. Marlow, and J. R. Lane. 1989. Influence of spotted knapweed *(Centaurea maculosa)* on surface runoff and sediment yield. Weed Technology 3:627-631.

Lang, R. F., R. D. Richard, and R. W. Hansen. 1997. *Urophora affinis* and *U. quadrifasciata* (Diptera: Tephritidae) released and monitored by USDA, APHIS, PPQ as biological control agents of spotted and diffuse knapweed. The Great Lake Entomologist 30:105-113.

Mays, W. T. and L. T. Kok. 2003. Population dynamics and dispersal of two exotic biological control agents of spotted knapweed, *Urophora affinis* and *U. quadrifasciata* (Diptera: Tephritidae), in southwestern Virginia from 1986 to 2000. Biological Control 27:43-52.

Myers, J. H. 2000. What can we learn from biological control failures? pp. 151-154. *In,* N. R. Spencer (Editor). Proceedings of the X International Symposium on Biological Control of Weeds. 976 pp.

Myers, J. H. and P. Harris. 1980. Distribution of *Urophora* galls in flower heads of diffuse and spotted knapweed in British Columbia. Journal of Applied Ecology 17:359-367.

Norwierski, R. M., J. M. Story, and R. E. Lund. 1987. Two-level numerical sampling plans and optimal subsample size computations for *Urophora affinis* and *Urophora quadrifasciata* (Diptera: Tephritidae) on spotted knapweed. Environmental Entomology 16:933-937.

Olson, B. E. and R. T. Wallander. 2001. Sheep grazing spotted knapweed and Idaho fescue. Journal of Range Management 54:25-30.

Pedigo, L. P. 1999. Entomology and Pest Management. 3rd Edition. Prentice-Hall Inc., Upper Saddle River, New Jersey. 691 pp.

Speight, M. R., M. D. Hunter, and A. D. Watt. 1999. Ecology of Insects: Concepts and Applications. Blackwell Science, Oxford, England. 350 pp.

Story, J. 2002. Spotted Knapweed. pp. 169-180. *In,* R. V. Driesche, B. Blossey, M. Hoddle, S. Lyon, and R. Reardon (Editors). Biological Control of Invasive Plants in the Eastern United States. US Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team FHTET-2002-04. 413 pp.

Story, J. M., K. W. Boggs, W. R. Good, L. J. White, and R. M. Nowierski. 1995. Cause and extent of predation on *Urophora* spp. larvae (Diptera: Tephritidae) in spotted knapweed capitula. Environmental Entomology 24:1467-1472.

Story, J. M., W. R. Good, and N. W. Callan. 1993. Supercooling capacity of *Urophora affinis* and *U. quadrifasciata* (Diptera: Tephritidae), two flies released on spotted knapweed in Montana. Environmental Entomology 22:831-836.

Watson, A. and A. J. Renney. 1974. The biology of Canadian weeds. 6. *Centaurea diffusa* and *C. maculosa.* Canadian Journal of Plant Science 54:687-701.

White, I. M. and V. A. Korneyev. 1989. A revision of the western Palaearctic species of *Urophora* Robineau-Desvoidy (Diptera: Tephritidae). Systematic Entomology 14:327-374.

Zar, J. H. 1999. Biostatistical analysis. 4th edition. Prentice-Hall Inc. Upper Saddle River, New Jersey. 663 pp.